# A METHOD OF STANDARDIZING THE COLOR VALUE OF THE DAYLIGHT ILLUMINATION OF AN OPTICS ROOM

By C. E. FERREE, G. RAND, and I. A. HAUPT, Bryn Mawr College.

In a previous article (Psychol. Rev. 1912, XIX, pp. 364-373) we have given a method of standardizing the intensity of light in an optics room illuminated by daylight and have described provisions for keeping constant the intensity selected as standard. If still more exact conditions are wanted for conducting work on color sensitivity another variable, namely, the changing color of daylight, should perhaps be taken into account. It is the purpose of this paper to describe a method of standardizing the color value of the daylight illumination of a room and of correcting the changing values to the standard value in such optics rooms as we have in our laboratory.

We mean by standardizing here only a means of matching the daylight selected as desirable and of reproducing at any given time as a standard the color value which matches the daylight selected. Our plan does not include primarily a means of determining what is the most desirable color value of daylight to use, although that might well be made a valuable feature of the plan. To be of the greatest service in psychological optics the plan should be both reasonably simple of accomplishment and have a fair degree of precision. In devising a method we have endeavored to keep both of these requirements in mind. Obviously the first step to accomplish is to have a source of light the color value of which can be kept constant within acceptable limits. A well seasoned tungsten light operated by a constant current gives a light of sufficient constancy of composition to serve our purpose.[1] It has

[1] In reply to an inquiry about the constancy of color value of the light emitted by the tungsten filament operated at a constant voltage, also its constancy as compared with the light emitted by the carbon filament, we have the following from the Bureau of Standards. "With regard to the constancy of the color from lamps operated at a constant voltage, it can be said in general that almost any seasoned incandescent lamp will burn a considerable time without any appreciable change in the color of the light, unless the filament is operated at a temperature above the normal. In comparing carbon with tungsten filaments the relative constancy will depend on the conditions. If the two are set at voltages which will give the same color, the tungsten will change much more slowly than the carbon In fact a tungsten filament operated at the normal color of carbon lamps will usually

the advantage too that its changes of color with change of voltage are roughly similar in direction to those which occur in daylight. A second step is to have a means of changing the color value of the light to match the daylight selected as desirable and a comparison surface on which to make the match. The first of these purposes can be accomplished by means of thin gelatine filters of known spectrum transmission, properly selected and combined to give the color values needed; and the second by means of any photometer head which presents a sufficiently good field for the comparison. We have already described a simple and inexpensive photometer for daylight work which with the proper selection of filters can also be made to serve the present purpose very well. For a description of this photometer the reader is referred to this Journal, 1916, XXVII, pp. 335-340. When the proper filters are inserted on the side next to the standard lamp this photometer can be used to make both the photometric and colorimetric comparison with no change either in the apparatus or the adjustment of the lamp. With the instrument set for the color and intensity of light selected as standard it can be determined at a glance whether the illuminaton of the room fulfills the desired requirements with regard to both of these features.

We have stated that the method employed should have a satisfactory degree of precision and sensitivity. In order to get some estimate of the sensitivity of the method or what amounts of color change can be detected at different intensities of illumination, the following experiments were conducted. (1) The light from two well seasoned tungsten lamps of equal watt value (40-watt, type B Mazda) was brought to a color and brightness match at the photometer head. The change in voltage required to produce a just noticeable change in color tone was then determined. The work was conducted in a dark room and for convenience in getting the proper range of intensities the photometer head was removed from its place in the box photometer and mounted on an ordinary photometer bar. In making the determinations one lamp, A, was operated at 107 volts and set at the desired distance from the photometer head. The other lamp, B, was operated at such a voltage and set at such a distance from the head as was needed to give an exact color and brightness match. When

burn thousands of hours with no appreciable change in color. Whether different lamps of the same kind give light of the same color depends on how closely the lamps are kept uniform in manufacture. As furnished on the market at present different tungsten lamps of the same size will be found to be more nearly alike than carbon lamps."

the match was obtained the voltage of lamp A was lowered until a just noticeable difference in color tone could be detected at the screen. A measure was thus had of the amount of color change that could be detected by the instrument in terms of the amount that is produced by a given variation of the voltage of a tungsten lamp the specification and the conditions of operation of which are known. When the voltage of lamp A was lowered the intensity as well as the color value of the light at the photometer head was changed. This required a resetting of the lamp B to bring the two photometric fields to equal brightness. However, as a check on the judgment of just noticeable difference in color tone each observation was made under more than one brightness relation between the two photometric fields. The judgment was not difficult to make. Its precision in fact compares very favorably with that of the photometric judgment. The determination was made with the lamps at different distances from the photometer head,—14, 20, 30, 40 and 50 cm. to give the differences in intensity at which it was desired to make the determinations of colorimetric sensitivity. For the sake of a comparison of the colorimetric sensitivity of the photometer heads more commonly used, the determinations were repeated with Lummer-Brodhun heads of the contrast and disappearance types. The results of these determinations are given in Table I.

TABLE I*

A COMPARISON OF THE SENSITIVITY OF DIFFERENT PHOTOMETER HEADS TO CHANGE IN COLOR OF LIGHT OF TUNGSTEN LAMP (MADZA TYPE B) OPERATED AT 107 VOLTS

| Distance of Lamp From Photometer Head (cm.) | Voltage Change of Lamp to Give Just Noticeable Change of Color Tone | | |
|---|---|---|---|
| | Lummer Brodhun Head Contrast Type | Lummer Brodhun Head Disappearance Type | Bunsen Head |
| 14 | 0.25 | 0.5 | 1.0 |
| 20 | 0.50 | 1.0 | 1.5 |
| 30 | 0.75 | 1.5 | 2.5 |
| 40 | 1.00 | 3.0 | 3.0 |
| 50 | 1.25 | 3.5 | 3.0 |

*The results of this and the following tables are for Observer R. The main points were verified by a check observer, H.

(2) In the second series of experiments a comparison was made of the sensitivity to change of color tone with the three photometer heads, the Bunsen and the two types of Lummer-Brodhun, when the photometric surfaces were illuminated by the tungsten lamps, natural color, and when they were illuminated by the light from these lamps filtered through gelatines so selected as to match the daylight in one of our optics rooms at 11 A. M. on a clear day. The intensity of light at the photometer head was made the same for both kinds of illumination. The comparison was made at three intensities of illumination, corresponding to those given by the tungsten lamps in the preceding set of experiments when placed at 30, 40 and 50 cm. from the photometer head. The comparison was not made for the other intensities because they could not be obtained on our photometer bar on account of the reduction in intensity produced by passing the light through the daylight filters. That is, the lamps could not be brought nearer to the photometer head than 14 cm. and to match the tungsten lamp at 30 cm. from the head, for example, the lamp in front of which the filter was placed had to be set at a distance of 14.3 cm. The results of this comparison are given in Table II.

TABLE II

A COMPARISON OF THE SENSITIVITY OF DIFFERENT PHOTOMETER HEADS TO CHANGE IN COLOR OF LIGHT OF TUNGSTEN LAMP (MADZA TYPE B) OPERATED AT 107 VOLTS AND OF THIS LIGHT FILTERED TO MATCH DAYLIGHT

| Distance of Lamp From Photometer Head Giving Equal Illumination for Each Intensity for | | Voltage Change of Lamp to Give Just Noticeable Change of Color Tone | | | | | |
|---|---|---|---|---|---|---|---|
| | | Type B Mazda Lamp | | | Type B Mazda Lamp With Daylight Filter | | |
| Type B Mazda Lamp | Type B Mazda Lamp With Daylight Filter | Lummer Brodhun Head Contrast Type | Lummer Brodhun Head Disappearance Type | Bunsen Head | Lummer Brodhun Head Contrast Type | Lummer Brodhun Head Disappearance Type | Bunsen Head |
| (cm.) | (cm.) | | | | | | |
| 30 | 13.5 | 0.75 | 1.5 | 2.5 | 0.25 | 0.50 | 0.75 |
| 40 | 18.8 | 1.00 | 3.0 | 3.0 | 0.25 | 0.50 | 1.00 |
| 50 | 25.2 | 1.25 | 3.5 | 3.0 | 0.25 | 0.75 | 1.50 |

(3) A somewhat limited comparison was made of the sensitivity of the Bunsen head to change in color tone when the photometric surfaces were neutral and when they were colored. This was done because the color of some pigments is known to be very sensitive to changes in color value of the

light falling upon them. For the purpose of making this comparison a number of such standard pigments as are commonly found in psychological laboratories were substituted for the white screen of the Bunsen head. Two cases were made of this investigation. (a) Six colored screens were used, selected from the Hering series of papers: the dark red, the orange, the yellow, the yellowish green, the blue-green and the violet; and three from the Milton-Bradley series: the red-violet, the red-violet, tint No. 1 and the orange-red, tint No. 1. The light from the 40-watt lamp was in each case passed through the daylight filter referred to above. The brightness of the photometric surfaces was kept constant in all cases at a value equal to that of the white screen illuminated by the filtered light of the tungsten lamp at a distance of 74 cm. This was the highest brightness that could be obtained with this lamp for the colored screen having the lowest coefficient of reflection. This intensity of illumination was selected in order that the colorimetric comparison should be made in all cases for the same brightness of surfaces compared. The results of this comparison are given in Table III. (b) Since in the preceding

TABLE III

A COMPARISON OF THE COLORIMETRIC SENSITIVITY OF THE BUNSEN PHOTOMETER HEAD WHEN PROVIDED WITH WHITE AND COLORED FIELDS—THIS COMPARISON WAS MADE WITH THE INTENSITIES OF LIGHT ADJUSTED TO GIVE IN ALL CASES THE SAME BRIGHTNESS OF PHOTOMETER FIELDS, NAMELY, THE BRIGHTNESS OF THE BLUE PIGMENT (PIGMENT WITH LOWEST COEFFICIENT OF REFLECTION) ILLUMINATED WITH THE HIGHEST INTENSITY THAT COULD BE OBTAINED WITH THE FILTERED LIGHT OF THE MAZDA TYPE B LAMP OPERATED AT 107 VOLTS

| Photometer Field | Distance of lamp (cm.) from photometer head giving brightness of colored fields equal to that of white field illuminated by this lamp with daylight filter at 74 cm. | Voltage change of lamp to give just noticeable change of color tone. |
|---|---|---|
| Yellowish-green | 43.0 | 1.0 |
| Violet | 15.1 | 2.0 |
| Red-violet | 22.6 | 3.0 |
| Orange-red, tint No. 1 | 40.0 | 3.0 |
| Red-violet, tint No. 1 | 33.5 | 4.0 |
| Yellow | 50.8 | 4.0 |
| Orange | 38.0 | 5.0 |
| Dark red | 31.5 | 6.0 |
| Blue | 13.8 | 6.0 |
| Blue-green | 27.3 | 8.0 |
| White | 74.0 | 4.0 |

experiments the pigments of the higher reflection coefficients had to be used at lower illuminations than the other pigments in order to fulfill the conditions that the colorimetric comparison should be made in all cases on surfaces of equal brightness, it was decided to make a comparison of the most favorable of these colors with the neutral screen at illuminations approximately equal to that used for the color of lowest reflection coefficient in the former experiments. This, it will be remembered, was the highest that could be obtained with the filtered light of the 40-watt lamp. For this purpose the yellowish green, the yellow and orange-red, tint No. 1, screens were used. The results of this comparison are given in Table IV. These results, it scarcely need be pointed out, have a

TABLE IV

A Comparison of the Colorimetric Sensitivity of the Bunsen Photometer Head When Provided With White and the More Sensitive Colored Fields Used in Table III, at Intensities of Illumination Equal Approximately to the Highest That Could be Obtained With the Filtered Light of the Type B Mazda Lamp Operated at 107 Volts

| Photometer Field | Distance of lamp (cm.) from photometer head giving equal brightness of white and colored fields for Mazda type B lamp with daylight filter | Voltage change of lamp to give just noticeable change of color tone |
|---|---|---|
| Yellowish-green | 16.5 | 0.25 |
| White | 26.5 | 1.50 |
| Yellow | 13.5 | 1.50 |
| White | 20.0 | 1.0 |
| Orange-red, tint No. 1 | 15 | 1.50 |
| White | 22 | 1.25 |
| Violet | 15.1 | 2.0 |
| White | 74 | 4.0 |

much more direct bearing on the problem of selecting screens for our standardizing instrument than those of the former comparison. That is, in the selection of screens for such instrument we are concerned with relative sensitivities at equal illuminations, not equal brightnesses, of screen. Obviously in the final selection of screens for any particular instrument that screen should be chosen which shows the greatest sensitivity for the range of illuminations possible for the instrument or for the range that is likely to be used.

An inspection of the results in Tables I-IV shows the following points.

(1) As might be expected smaller color changes could be detected at the higher than at the lower intensities of illumination. That is, at the higher intensities the color of the light was less saturated (the inhibitive action of the achromatic on the chromatic component of the retinal excitation) therefore a smaller change was needed to be just noticeable.

(2) The colorimetric sensitivity of the photometer heads employed is in the following order from greatest to least,—the Lummer-Brodhun, contrast type; the Lummer-Brodhun, disappearance type; the Bunsen. As bearing on the type of field that gives high colorimetric sensitivity such comparisons are of importance to colorimetry by the monochromatic method.

(3) Smaller changes of voltage were required to produce a noticeable change in the color of the light filtered to match daylight than in the color of the unfiltered light of the Mazda type B lamp.

(4) Of all the colored screens employed the yellowish-green, the violet, the yellow and the orange-red, tint No. 1, showed greater sensitivity to changes of color of light of the type produced in these experiments (changes similar to those which occur in daylight) than the white screen when the comparison was made at equal brightness of screen. When, however the comparison was made at illuminations approximately equal to the highest illumination that could be obtained with the filtered light of the 40-watt lamp only the green showed a greater colorimetric sensitivity than the neutral screen. The green screen seemed to be peculiarly sensitive to the changes which are produced by adding the longer wave-lengths to daylight. That is, the adding of the red wave-lengths appeared to decrease the saturation of the green and the adding of the yellow wave-lengths, to increase the yellow component already present. At the highest intensity of illumination used a change of only 0.25 volt was needed to cause a noticeable change in the color of the screen. Indeed at this intensity of illumination the colorimetric sensitivity of the Bunsen head was so much improved by the substitution of the green screen as to equal that of the more sensitive of the two Lummer-Brodhun heads with the white screen.

As we have already indicated the work of standardizing

for color value and intensity may be done at the same time. It may be accomplished as follows: A daylight is selected of the color value and intensity desired. On the side of the photometer head next to the standard lamp gelatine filters are inserted so chosen that when the light from this lamp run at a given voltage and set at the position on the bar needed to give the intensity match, is filtered through them, the photometric surfaces illuminated by this light match in color value the surface illuminated by the daylight. To reproduce this standard at any future time all that is needed is to reset the lamp in the same position on the bar and to reproduce the voltage. With the photometer set up at the point of work in the room or as near to it as possible, the process of checking up the illumination both as to color value and intensity becomes very simple. A glance at the photometric field is sufficient to give the desired information. Since it is not so easy to arrange for the correction of daylight to the color value chosen as standard as it is to correct the intensity, feasibility may dictate that the work be done within a certain range of variation of color value. The apparatus recommended may be used to standardize this range as follows: If the daylight chosen as desirable be that of skylight near the middle of a clear day the changes that are apt to occur during the course of the day or from day to day may be approximated roughly by lowering the voltage of the standard lamp or by lowering the voltage supplemented by the addition of one or more of the thin gelatine filters properly selected. When this is done and the lamp is reset to compensate for the change of intensity produced, a range of variation of color value is fixed within which the daylight illumination must fall or be rejected for the particular work in hand. In such a case the photometer is set so that the standard surface in the photometer head is illuminated with the light chosen as the limit towards which the color value may vary and still be accepted for the work in hand. It is very easy then at any particular time to judge whether the dominant color of the daylight incident upon the receiving surface of the photometer falls within the limiting value.

Obviously a means of correcting the changing daylight to the color value chosen as desirable would be an advantageous supplement to the work of standardizing. The method we purpose for use for this is as follows: At a distance above the diffusion sash of ground glass installed beneath the sky-

light in our optics rooms, sufficient to give a good spread of light, will be installed opaque pendant reflectors of the distributing type. These reflectors will be supplied with filters which transmit an excess of the short wave-lengths. They will be installed on separate circuits, one or more to the circuit, so that a variable proportion of the artificial light may be used as is needed. Further to vary both the composition and the amount of artificial light used, wall rheostats will be included in as many of the circuits as is found to be advisable. Quite a wide range of composition and intensity of light can be obtained also by the use of lamps of different types and wattages. The artificial units may be installed well out of the road and the desired direction and throw of light be obtained by the shape of the reflector and the angle at which it is installed. Further the amounts of daylight used in getting the desired composition may be controlled by a system of curtains placed under the skylight above the diffusion sash and the artificial units. The elaborate system of curtains which is already installed beneath the diffusion sash in our rooms will serve as they do now for fine gradations of intensity of light and may prove useful to some extent perhaps for the control of the composition.

An alternative to a flexible system of correction of actual daylight for both composition and intensity is the utilization of some one of the artificial daylights which are now on the market. Of the unfiltered sources the carbon dioxide tube gives perhaps by common agreement the closest approximation to skylight. Its cost, however, is prohibitive for the greater number of laboratories. The same thing might well be said of the best of the filter units. The ones most familiar to us all and the most available from the standpoint of cost are the blue bulb lamps. With regard to these lamps, however, only a rough approximation to daylight is claimed. We have thought that it may be of interest to show here a spectrophotometric comparison of one of them, the type C-2 Mazda lamp, and of some of the closer approximations to daylight, with the black body at 5000 degrees absolute which is sometimes taken as the standard of average daylight. (See Fig. I.) For the comparative curves given in this figure we are indebted to the Electrical Testing Laboratories, 80th street and East End avenue, New York City. The comparison here, it will be remembered, is photometric, not colorimetric.

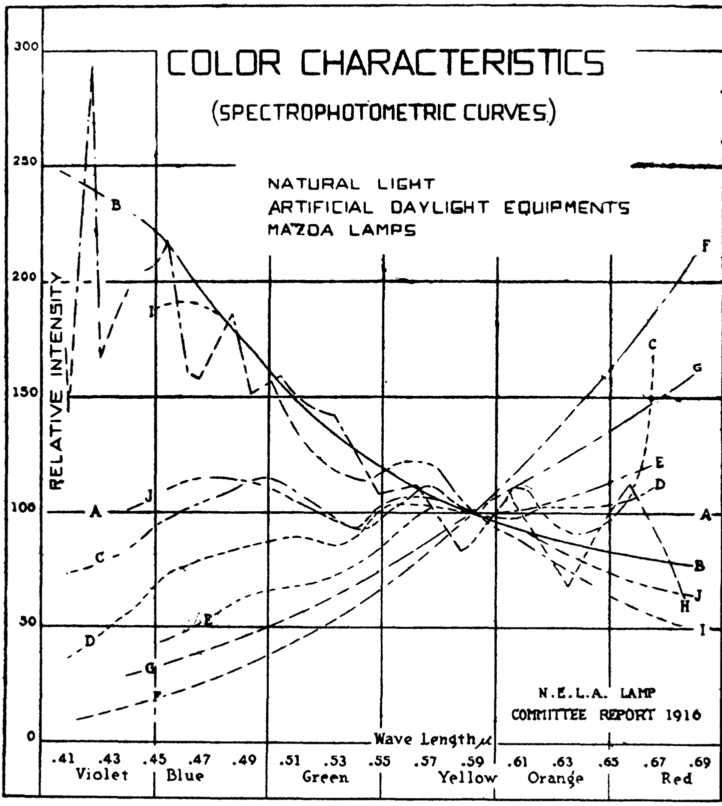


FIG. I

A—Black body at 5000 degrees absolute ("Average Daylight")
B—Blue sky (Ives) I. E. S. Transactions, 1910, p. 208.
C—Daylight glass with Mazda C lamp (Brady) I. E. S. Transactions, 1914, p. 952.
D—Bluish glass with Mazda C lamp (Sharp) I. E. S. Transactions, 1915, p. 220.
E—Mazda $C_2$ lamp.
F—Mazda B lamp (7.9 lumens per watt).
G—Mazda C lamp (20 lumens per watt).
H—Moore tube (Paper read before I. E. S. November 11, 1915).
I—Trutint glass, (Luckiesh) I. E. S. Transactions, 1914, p. 839.
J—Trutint glass, (Luckiesh) I. E. S. Transactions, 1914, p. 839.